TECHNICAL REPORT AMR-IN-05-01

AUTOMATED TARGET RECOGNITION AND FRATRICIDE REDUCTION

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March 2006

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REPORT DOCUMENTATION PAGE

Form Approved OMB No. 074-0188

1. AGENCY USE ONLY	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	March 2006	Final

4. TITLE AND SUBTITLE
Automated Target Recognition and Fratricide Reduction

5. FUNDING NUMBERS

6. AUTHOR(S)
Bruce W. Fowler, Ph. D. and William C. McCorkle, Ph. D.

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Commander, U. S. Army Research, Development, and Engineering Command
ATTN: AMSRD-AMR-IN
Redstone Arsenal, AL 35898-5000

8. PERFORMING ORGANIZATION REPORT NUMBER
TR-AMR- IN-05-01

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSORING / MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE
A

13. ABSTRACT *(Maximum 200 Words)*

Fratricide (or amicide) is a terrible consequence of combat operations. Often fratricidal consequences cannot be quantified directly or easily. Current research and development efforts are oriented to provide increased capability to automatically recognize targets, which offers to further complicate the fratricide situation. This report details a methodology, based on cost as a consequential approximation, for thresholding Automated Target Recognition (ATR) systems under combat conditions to minimize the impact of fratricide. Example computations using a simple enumeration simulation are presented to illustrate the application of the methodology.

14. SUBJECT TERMS
Guided Munitions; Military Operations, Strategy and Tactics; Guided Missiles; Optical Detection & Detectors; Automated Target Recognition (ATR)

15. NUMBER OF PAGES
32

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	SAR

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102

ACKNOWLEDGMENT

The authors wish to gratefully acknowledge the review of this work by Dr. Robert Sims with several useful recommendations and comments.

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I. INTRODUCTION

Then let the battle rage and onward move,
Count not the cost nor falter in the breach, [Young 1918]

Fratricide—the killing of brother soldiers—and amicide—the killing of friends, either allies or neutrals—can have a considerable impact on the prosecution of war. Previous analyses of fratricide (and amicide, hereafter not distinguished) have identified two general forms: [Fowler 2004, "Fratricide and Amicide," Chapter 57]

- Type 1, fratricide by misadventure; and
- Type 2, fratricide by misinformation.

Those analyses identified two basic models of fratricide, one of each type. Both models are stochastic in nature. The Type 1 model identifies the probability that a friendly element[1] or entity will be present in the lethal region of a weapon (nominally a volley or bomb strike.) The Type 2 model identifies the probability that a friendly element will be mis-recognized to be an enemy element. These models then integrate with standard attrition calculation methodologies to enable simulations of expected (or sampled) fratricide losses.

Automatic Target Recognition (ATR)—aka Automated Target Recognition, Aided Target Recognition, and so forth—is a natural extension of electronic combat sensors. In effect, ATR may both reduce and increase fratricide. By assisting a human operator in recognizing that an observed entity is indeed a target, it may reduce the amount of fratricide by reducing the likelihood that a friendly entity is perceived to be an enemy. When used as an adjunct or enabler of smart weapons [Heaston Smoots 1983] operating as the solitary means of recognizing a target, the situation is mixed. As compared to an artillery barrage of insensate rounds, fratricide is less likely; as an independent source of a decision to attack an entity, fratricide becomes a possibility.

The intent of this report is to go beyond simulation of the extent of fratricide and address how we may use the technical aspects of ATR to respond to battlefield conditions.

II. AUTOMATED TARGET RECOGNITION MODEL

A fairly simple ATR model considers only two types of elements: one each of friendly (F) and enemy (E). The simplicity arises in that there is assumed to be one observable x, which is treated as a Random Variable (RV). The density of observation of a particular value of x is represented by well defined Probability Density Functions (PDF) $p_F(x)$ and $p_E(x)$. Elaboration of the model by the introduction of more variables (observables) is

[1]Element in this case has a somewhat plastic meaning. It may be an individual or a vehicle or even a building.

straightforward and constitutes the means by which we may limit our attention to this simple model.

Although perhaps somewhat questionable, the two elements' observables are assumed to be independent. We do, however, assume that the overlap of the PDF is, in general, not null. That is,

$$0 < \int_{-\infty}^{\infty} p_E(x) \ p_F(x) \ dx < \infty. \tag{1}$$

This is a condition whose importance will emerge as we continue. This architecture is shown in Figure 1.

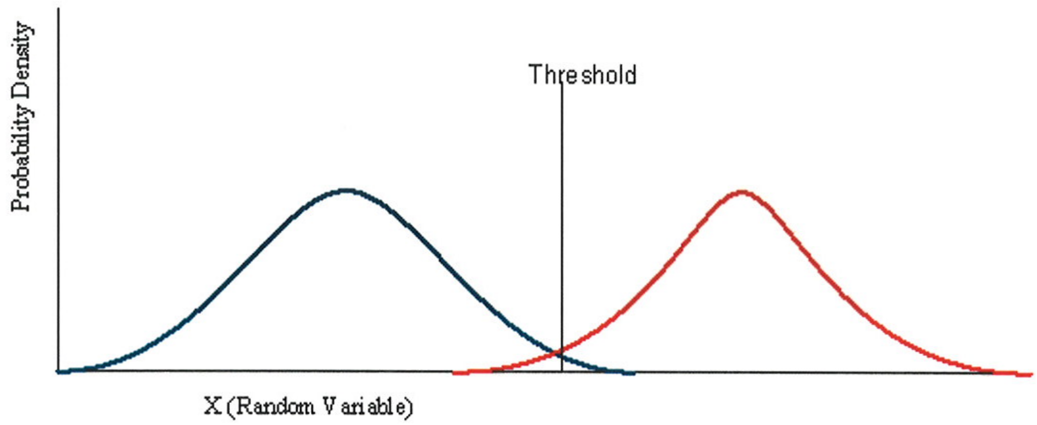

Figure 1. Plot of F, E PDF With Figurative Threshold

In implementing an ATR scheme, a threshold value of x is established. We designate this threshold value as z. In general, the threshold is a minimum.

For the sake of simplicity or presentation, we now prescribe that $\langle x_F \rangle < \langle x_E \rangle$, where $\langle x_I \rangle \equiv \int_{-\infty}^{\infty} x \ p_I(x) \ dx$, is the expected or mean value of the RV for each of the two distributions, respectively. We also avail ourselves of the corresponding standard deviations, σ_F, σ_E, which are defined in the usual manner.

We recognize that there is no necessary cause of this ordering of means. The situation could be the opposite. In either case, we would know the situation *a priori*. Thus, if the order of the means were reversed, that situation would only be a parametric variation that we need not elaborate in detail.

We also do not elaborate the situation where the two means are effectively identical and not resolvable. That is, the equivalent of Rayleigh's criterion is not satisfied.[Meyer-Arendt 1972, p. 185ff.]

With this prescription, we may define a set of four probabilities: the probability (for some value of the threshold z) that an element E will be accurately perceived (True Positive),

$$P_{TP}(z) = \int_{z}^{\infty} p_E(x)\ dx; \tag{2}$$

the probability that an element F will be accurately perceived (True Negative),

$$P_{TN}(z) = \int_{-\infty}^{z} p_F(x)\ dx; \tag{3}$$

the probability that an element F is inaccurately perceived to be an element of type E (False Positive),

$$P_{FP}(z) = \int_{z}^{\infty} p_F(x)\ dx; \tag{4}$$

and the probability that an element E is inaccurately perceived to be an element of type F (False Negative),

$$P_{FN}(z) = \int_{-\infty}^{z} p_E(x)\ dx. \tag{5}$$

Of particular interests are the probabilities that an element of type E is accurately perceived and that an element of type F is inaccurately perceived to be an element of type E. These cases are sometimes referred to as True and False Positives in association with their corresponding probabilities.

We note that in terms of Type 2 fratricide we have the associations: probability of True Positive equals probability of perceiving an element to be enemy given it is an enemy; True Negative equals perceiving friendly given friendly; False Positive equals perceiving enemy given friendly; and False Negative equals perceiving friendly given enemy.

Except as specifically noted, we shall generally use Gaussian (normal) PDF for illustrative purposes. Further, in the interest of some continuity of comparison, we adopt an illustrative model case with friendly, enemy means of 1.0, 5.0 and standard deviations of 1.5, 2.5, respectively.

As such an illustration, we present the True and False Positive Probabilities (plotted versus threshold) for this model in Figure 2.

We may identify three regions of interest in this figure. Proceeding from left to right, the first region is where both probabilities are essentially one. In this region, our sensor will essentially see all elements. If we were to set the threshold in this region, we would in effect perceive enemies and friendlies to be enemies in direct proportion to their numbers in the battle area.

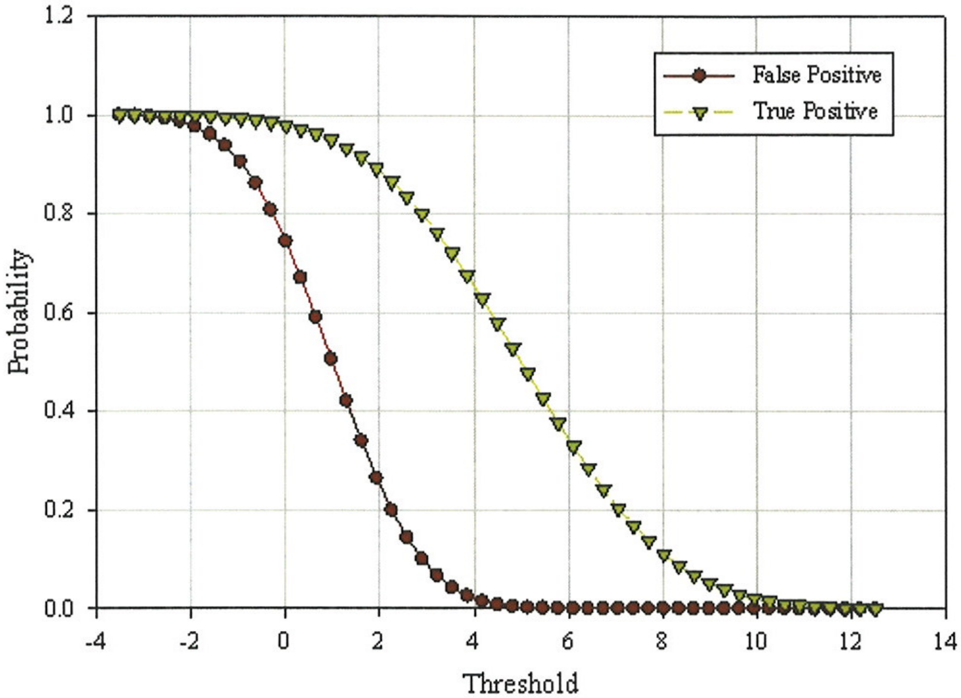

Figure 2. Probability of True and False Positive Versus Threshold

The second region is here both probabilities vary from essentially one to essentially zero. Because the distributions have different means and standard deviations, the curves are different here. This is the region of primary interest in our consideration so we shall defer discussion briefly.

The third region is where both probabilities are essentially zero. In this region, we see few elements in the battle area, either enemy or friendly. If we set our threshold in this region, however, all that we do see, enemy or friendly, we will perceive to be enemy.

In regions one and three, we have little control over separating enemies from friendlies. The degree of fratricide, consistent with a random sampling activity, will essentially be determined by the demographics of friendly and enemy elements. That is, if half of the elements in the battle area are friendly, then half of the engagements will be fratricidal. For region one, because the probabilities are essentially one, any element looked at will be recognized. Thus, in this region there will likely be many engagements and thus many kills. For region three, the probabilities are essentially zero, so few elements will be seen. Thus, in this region there will likely be few engagements and thus few kills.

If we set the threshold in region one, then we see all of the elements present but we cannot distinguish friend from foe very well. Thus, we would kill many enemies but also many friends. If we set the threshold in region three, then we see few of the elements and we still cannot distinguish friend from foe very well. Thus we would kill few friends but also few enemies. Indeed the fraction of fratricidal kills would be essentially the same as the fraction of friendly elements in the battle area.

This is why region two is the one of primary interest. Because we have restricted our consideration to the particular case where the friendly mean is less that the enemy mean, we have a particular relational architecture. If this case were reversed, the relational architecture would simply be mirror-imaged.

In region two, because of this restriction, we have the True Positive Probability curve falling off for larger value of threshold than the False Positive Probability curve. Intuitively, then, we may see the "tuning" problem to be one of picking the "right" value of the threshold to maximize the value of the True Positive Probability while minimizing the value of the False Positive Probability.

The assumption of well defined distributions is critical since it permits *a priori* estimation of a threshold. In practice, this may not be the case. Combat evolution may render the distributions nonstationary, and battlefield collection of significant data may be problematic.

III. PREVIOUS APPROACHES

The problem of "tuning" recognition is not a new problem, nor is it limited to defense applications. In particular, the problem seems common with medical practice. [Pickard 2004] In this section, we review two previous approaches, characterized by their methodologies. These are the Receiver Operating Characteristic (ROC) curve and the Probability Cost Function (PCF).

A. Receiver Operating Characteristic (ROC) Curve

The ROC curve is simply the plot of the True Positive versus the False Positive. This curve displays a couple of implied assumptions, namely that the E PDF has larger mean than the F PDF, and that the Cumulative Distribution Functions (CDF) are monotonically increasing. An example of a ROC curve calculated using our illustrational model is shown in Figure 3.

We immediately recognize that the area under the ROC curve

$$\begin{aligned} Area &= \int_0^1 P_{TP}\left(P_{FP}\right)\ dP_{FP} \\ &= \int_{-\infty}^{\infty} P_{TP}\left(x\right)\ P_{FP}\left(x\right)\ dx, \end{aligned} \tag{6}$$

is just the probability that a True Positive occurs "before" a False Positive, that is, for a lesser value of the RV. [Taylor 1983, pp. 380-387, and references therein.]

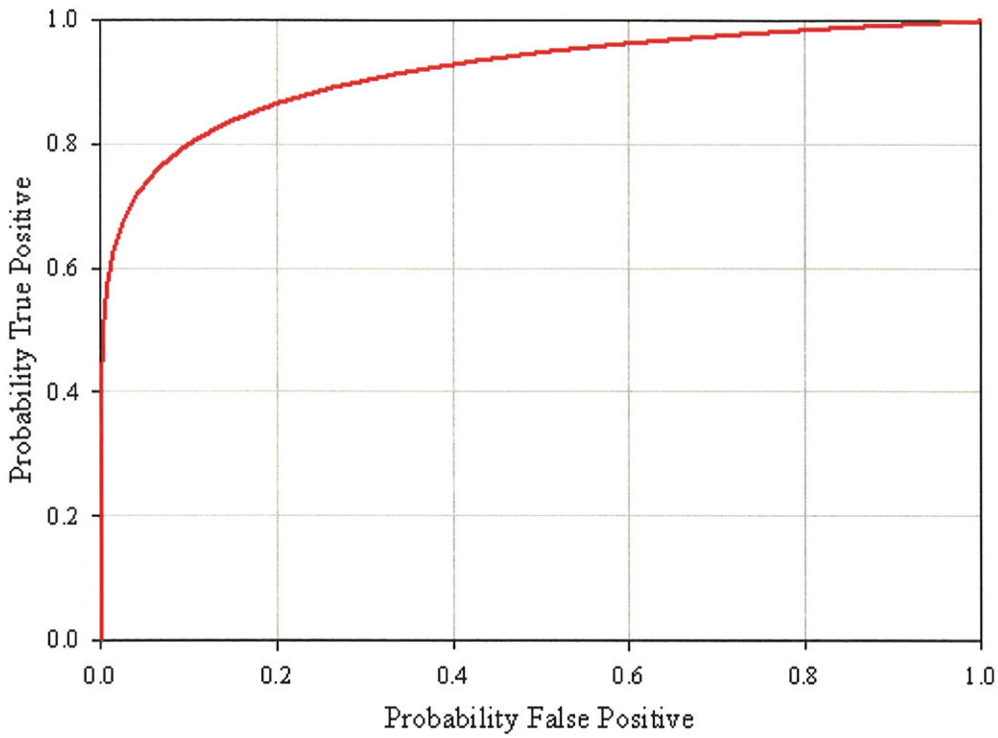

Figure 3. Example of an ROC Curve

The ROC curve is somewhat naturally obtuse. A considerable literature is devoted to explaining ROC curves. [Fawcett 2003] [Flach 2003] [Provost Foster 2001] Part of this obtuseness is the nature of the plot, which is a cross plot of True versus False Positive Probability. Thus, in our example, sweeping across Figure 3 from left to right is the result of sweeping across Figure 2 from right to left. Of course, this is an artifact of our prescription that we would only consider the case where the friendly mean is less than the enemy mean. Thus, while the ROC curve transcends this prescription, it is still somewhat confusing.

While the area under the ROC curve has meaning, [Fawcett 2003] it is not clear that this direct meaning is what we need for our endeavor. To give a minimum of insight into the ROC curve, consider the difference function

$$D\left(x\right) = P_{TP}\left(x\right) - P_{FP}\left(x\right). \tag{7}$$

This difference function has the merit that it begins to address the instinctual desire to maximize the True Positive Probability and minimize the False Positive Probability. This difference function is an approximation to this in that it (for example) maximizes the difference of the two probabilities.

We present an illustrative model plot of this difference function in Figure 4. Our first observation is that the classroom claim that the difference of two Gaussian processes is itself a Gaussian seems accurate. Our second is that, happily there is an extremum and it is a maximum. But what does this have to do with the ROC curve?

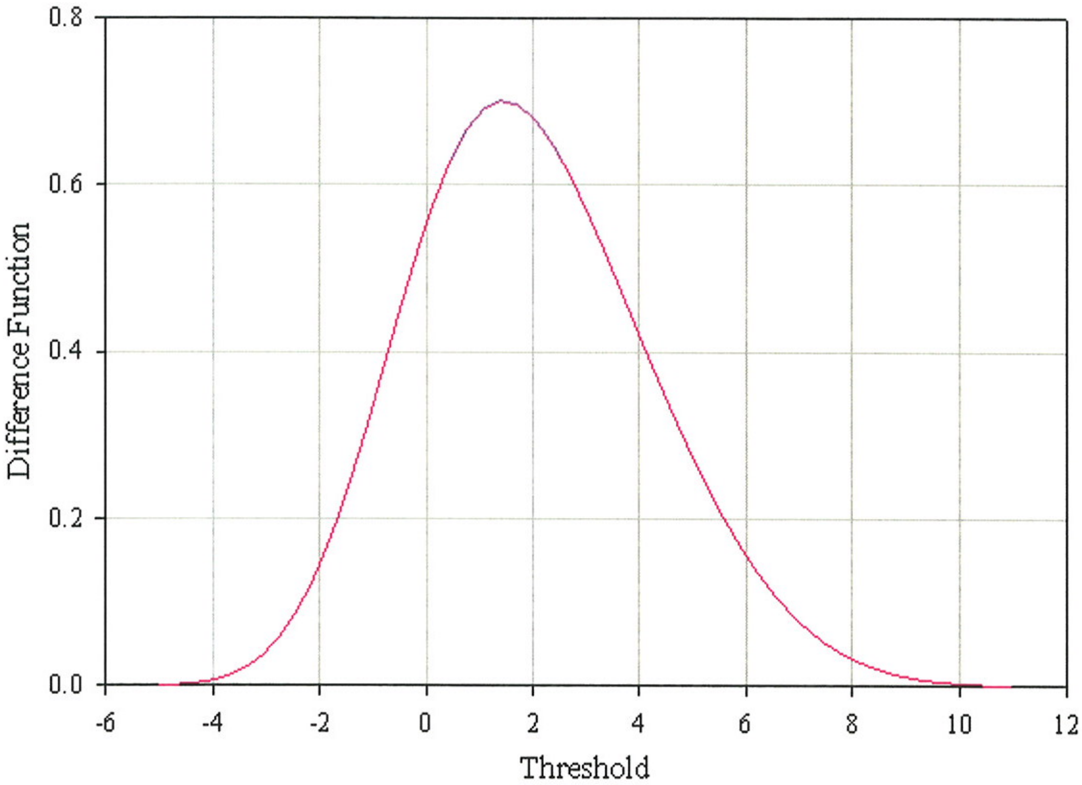

Figure 4. Difference Function Versus Threshold

To address this, we add this difference function to the plot of the ROC curve, Figure 3. This is presented in Figure 5. We immediately see that the maximum of the difference function corresponds to the knee of the ROC curve.

While the ROC curve embodies useful information and that information appears necessary for our investigation, the curve has some fundamental limitations that we should like to address. In particular, it seems important that we be able to address the consequences of both True and False Positives in a controlled fashion. This does not mean that the ROC curve has not had, nor continues to have a strong role in contributing to the development of ATR. [AMRDEC 2004] [Meadows 2005] However, since the basis of the ROC curve is the simple detection performance of the sensor, it does not give us the flexibility we need to

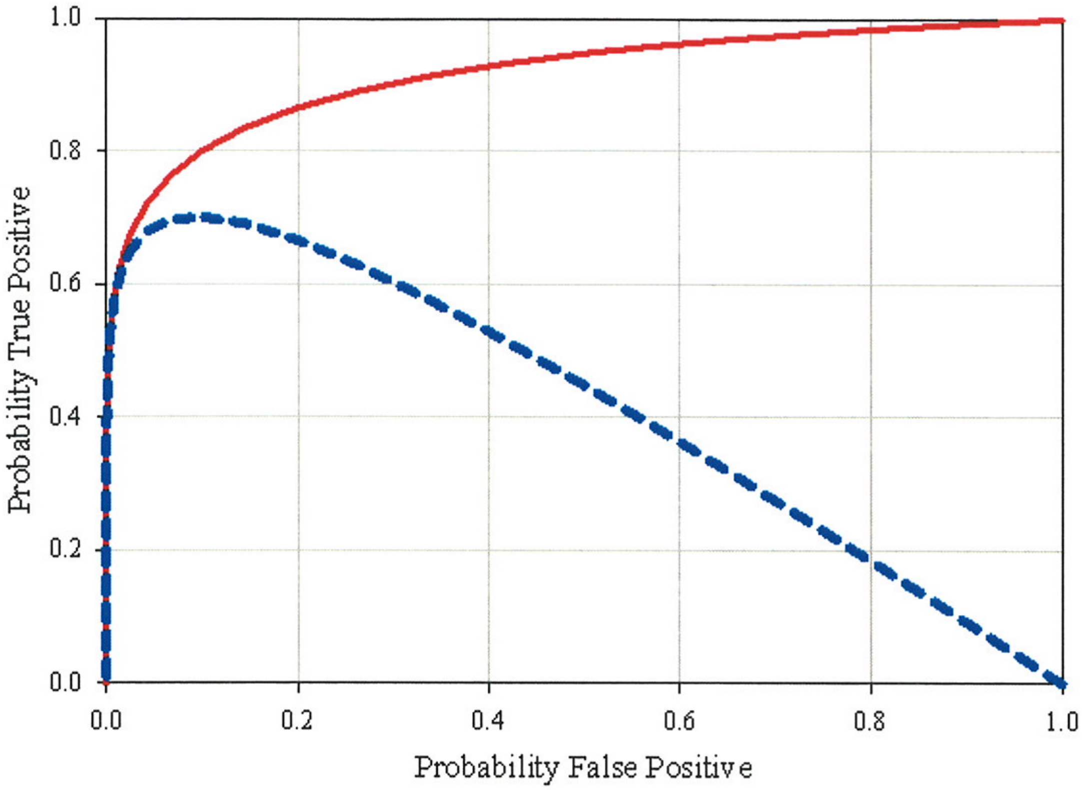

Figure 5. Plot of ROC Curve and Difference Function Versus False Positive Probability

achieve the desired consideration of fratricidal conditions.[2]

The second approach that we review begins to address this consideration by including the cost of these perceptions.

B. Probability-Cost Function

The PCF was introduced as a better means to address classifier performance than a ROC curve.[Drummond Holte 2000] [Drummond Holte 2004] This function is developed by starting with an expected cost

$$\langle C \rangle = P_{FN} P(Y) C_{FN} + P_{FP} P(N) C_{FP}, \tag{8}$$

where: $P(Y), P(N)$ = the probability the entity examined (classified) is actually a Y or an N, respectively; and C_{FN}, C_{FP} = the cost of a False Negative, False Positive, respectively. We note in passing that since the True Positive, Negative costs are absent, they have been

[2]As we shall see subsequently, if we modify the ROC curve to reflect cost, the resulting form becomes applicable.

neglected for some reason. One possibility is that only "error" costs are being considered. Also note that dependence on the random variable has been suppressed.

Since $P_{FN} = 1 - P_{TP}$, this may be rewritten as

$$\langle C \rangle = (1 - P_{TP}) P(Y) C_{FN} + P_{FP} P(N) C_{FP}, \tag{9}$$

we may immediately see that this expected cost is maximal when there are no True Positives and all False Positives ($P_{TP} = 0, P_{FP} = 1$). Thus, the maximum possible cost (in this model) may be written as

$$\langle C \rangle_{\max} = P(Y) C_{FN} + P(N) C_{FP}. \tag{10}$$

The normed cost may then be defined as

$$\langle c \rangle \equiv \frac{\langle C \rangle}{\langle C \rangle_{\max}}, \tag{11}$$

which lies on $[0, 1]$.

If we now defined the PCF as

$$PCF_X = \frac{P_X C_X}{\langle C \rangle_{\max}}, X = FN, FP, \tag{12}$$

then the normed cost may be written as

$$\langle c \rangle = \sum_{X=FN,FP} PCF_X. \tag{13}$$

IV. THE COST OF AUTOMATED TARGET RECOGNITION

The previous developments present some difficulties in assessing the cost of ATR. In particular, we may be concerned about the absence of any cost associated with making correct classifications. Further, while normalization is useful in comparing classifiers, minimization of the cost of the operation may be more directly applicable to our problem. Certainly it is clearer to the authors.

A. The Nature of Automated Target Recognition Cost

In most defense analyses, cost is synonymous with an amount of money. Occasionally, some other measurable is used, but the most common one is money.

This can present some challenge. Most particular is the question of how much is a human worth? This is a very difficult question. The value of a son/father (for example) to a family, friends, and local community is not strictly monetary.

The cost of human life is often treated as the direct cost of loss. This has a certain validity since it is an actual cost, and since we cannot analytically represent other costs, we often make do with what can be done. We recognize this as a limitation or approximation. We also acknowledge that there are circumstances that arise where quantitative assessment is inadequate.

The fratricide situation is often one such. Fratricide can have a high cost in terms of unit morale or public support of the "other means." [Clausewitz 1976] Amicide can have a high cost in terms of loss of support of allied and nonaligned states or alienation of public approval. Both of these may have political or economic costs.

At the same time, however, avoidance of fratricide may have cost. In particular, exercising additional care to avoid fratricide and amicide may present new opportunities to enemies to inflict damage and loss. In the vernacular, this is a situation of "damned if you do, damned if you don't."

Recognizing this two-edged nature and the difficulty of quantifying certain costs, we may identify two extreme states with respect to fratricide. One state, which we may characterize as fratricide ignoring, corresponds to situations where military effect is unconditionally necessary to assure survival. In such a situation, fratricide, however regrettable, must be accepted as part of the cost of survival. The other state, which we may characterize as fratricide averse, corresponds to situations where no amount of fratricide may be tolerated. In such a situation, inimicidal[3] loss, however damaging, must be accepted as part of the cost of war.

These states, which are simultaneously callous and idealistic, are useful because they provide a means of approximating the costs of fratricide for analysis, and thereby provide insight into how we may minimize fratricide and/or inimicide.

B. Expected Cost

At this point, we want to examine the "cost" of the operation (or use) of the ATR system. To do this, we need to know three sets of quantities. The first set is the probabilities that enemy or friendly elements are perceived to be enemy or friendly elements. These probabilities are nothing more than the True, False Positive, Negative Probabilities that we have already elaborated.

The second set of quantities we need are the probabilities that when an element is looked at, it is enemy or friendly. We designate these probabilities as $P(E), P(F)$.

Finally, the third set of quantities that we need are the costs associated with the consequences of each perception. We label these as $C_I, I = TP, FP, TN, FN$. We implicitly assume here that some action (or inaction flows, at least potentially) from each type of perception and thus incurs a cost.

[3]Inimicide - the killing of friendly by enemy.

On this basis, then we may write the expected cost (of a particular threshold value) as

$$\begin{aligned} \langle C \rangle (x) &= P(E)\left[P_{TP}(x)\, C_{TP} + P_{FN}(x)\, C_{FN}\right] \\ &\quad + P(F)\left[P_{FP}(x)\, C_{FP} + P_{TN}(x)\, C_{TN}\right] + C_{Common}, \end{aligned} \tag{14}$$

where the only cost not defined is C_{Common}. We defer this definition until we consider actual estimation of the expected cost. It is appropriate, however, to address some implicit assumptions and conditions.

First, the expected cost is the cost per perception carried through to some reasonable conclusion. Second, we ignore how the battle area is searched, treating element selections as uniformly random. Lastly, we presume the costs to be independent of threshold, largely because we have not been able to identify any obvious relationship.

It is tempting to attempt to minimize this cost in the anticipation that we may find a value of threshold that uniquely provides this minimum. Such a calculation is mathematically feasible but not always meaningful. Thus, we shall have to proceed with direct examination of the expected cost. However, since our purpose is to identify trends toward limiting states, this is not a great handicap.

C. Demographics of E and F

In the ATR problem posed, we are dealing with two populations, represented here by E (targets or enemy), and F (friendly, allies, neutrals, and so forth, but not enemies). For convenience, we assume that the battle area contains n_E, n_F elements of each. We also assume that these elements are randomly distributed in the battle area n a uniform manner.

The probabilities $P(F), P(E)$ on pure frequentist grounds are

$$P(F), P(E) = \frac{n_F}{n_E + n_F}, \frac{n_E}{n_E + n_F}, \tag{15}$$

respectively. As stated earlier, we are assuming that we do not have to worry about sampling order. The extension to a more diverse demographic is straightforward, but, we believe, presents an unnecessary complication.

D. Perception Cost Estimates

We now address the matter of estimating the costs of the perception types. As we have already indicated, we recognize that some of these costs cannot be counted accurately because they cannot be expressed in the same terms as are used for most costs. Instead we will approximate these costs in the same terms carried to the extremes of being vanishingly small or overwhelmingly large to represent whether those costs can or must be borne or can or must be avoided.

For simplicity of consideration, we will treat each perception as precipitating some action. If this action is an engagement, we assume adequate capacity and capability to effect a kill.

1. False Negative Cost

This is determining that an enemy element is a friend. As a result, we give the enemy opportunity to wreck harm on us and we incur a cost of replacing our losses. Since we are dealing with expected values, we may estimate this cost from an average amount of damage that an enemy element exacts on the friendly force. Thus,

$$C_{FN} \simeq \langle C_{loss} \rangle \,. \tag{16}$$

As an estimate, we may take the average number of combat systems lost to a single enemy system times their replacement costs (with or without crew, as appropriately determined.) We note that the human loss here is non-fratricidal.

2. True Positive Cost

Previously in the PCF formalism, the cost of a True Positive was taken to be zero. For our ATR situation, this would not seem to apply. For a True Positive, we perceive an enemy element to be an enemy. Under nominal circumstances, we would engage the element and presumably kill it. Thus we incur a positive cost of the kill, and a negative cost of avoiding the loss described above in the False Negative case,

$$C_{TP} \simeq C_{kill} - \langle C_{loss} \rangle \tag{17}$$

3. True Negative Cost

Again, previously this cost was zero. For the True Negative, we perceive a friendly element to be friendly. As a result, we probably do not take any action. Thus, we may approximate this cost as

$$C_{TN} \simeq 0. \tag{18}$$

4. False Positive Cost

The False Positive is much more subjective. In this case, we perceive a friendly element to be an enemy. On this basis, we engage the element and consistent with our earlier assumption, we kill it. Thus we incur two costs, the cost of the kill and the cost of the fratricide. As we have already stated, this cost is difficult to represent in the same terms as the other costs. For now, we merely express this cost symbolically and describe our specific treatment when we take up computation. The form of the cost is

$$C_{FP} \simeq C_{kill} + C_{Fratricide}. \tag{19}$$

E. Common Cost

The remaining cost, which we now define, is the common cost. This is the cost associated equally with all four perceptions. We may specifically identify the cost of operating the ATR system as a common cost.

Since we will be primarily interested in the behavior of the expected cost under different variations, we can fairly reliably ignore this cost. Were we concerned with absolute values of the expected cost, we could not do this.

F. Collecting the Cost

At this point, we want to specify the form of the expected cost to reflect how we have developed the specific costs. For simplicity, we also want to reduce the number of perception probabilities. We start with

$$\begin{aligned} \langle C \rangle (x) &= P(Y) \left[P_{TP}(x) C_{TP} + P_{FN}(x) C_{FN} \right] \\ &\quad + P(N) \left[P_{FP}(x) C_{FP} + P_{TN}(x) C_{TN} \right] + C_{Common}, \end{aligned} \tag{20}$$

and eliminate the probabilities of False and True Negatives using the completeness relationships implied in Equations 2 through 5. This gives us

$$\begin{aligned} \langle C \rangle (x) &= P(Y) \left[P_{TP}(x) C_{TP} + (1 - P_{TP}(x)) C_{FN} \right] \\ &\quad + P(N) \left[P_{FP}(x) C_{FP} + (1 - P_{FP}(x)) C_{TN} \right] + C_{Common}, \end{aligned} \tag{21}$$

which we may rearrange as

$$\begin{aligned} \langle C \rangle (x) &= P(Y) \left[P_{TP}(x) (C_{TP} - C_{FN}) + C_{FN} \right] \\ &\quad + P(N) \left[P_{FP}(x) (C_{FP} - C_{TN}) + C_{TN} \right] + C_{Common}. \end{aligned} \tag{22}$$

We now take advantage of Equations 16 through 19 to explicitly express the individual perception costs, giving us

$$\begin{aligned} \langle C \rangle (x) &= P(Y) \left[P_{TP}(x) (C_{kill} - 2 \langle C_{loss} \rangle) + \langle C_{loss} \rangle \right] \\ &\quad + P(N) \left[P_{FP}(x) (C_{kill} + C_{Fratricide}) \right]. \end{aligned} \tag{23}$$

V. COUNTING THE COSTS

At this point, we proceed from equations to numbers so that we may gain some insight into the application of the model.

A. Estimating Costs

First, it is necessary to elaborate some numeric costs that are approximations of actual amounts of money. We elaborate our illustrative model with these by norming loss cost to 1.0 and kill cost to 0.1. This ratio of kill-to-loss may be rather large, but for now, we want to maintain significance of the kill cost. We parametrize fratricide cost in terms of the loss cost from essentially nil to very large.

We further parametrize based on the presence of friendlies in the area of operation as a percent of total elements. Sample computations for these two parametric variations are presented below.

B. Few Friendlies

Cost computations for few friendlies, specifically 10 percent of the elements in the battle area, are presented in Figure 6. It may be noted immediately that until the fratricide cost is greater than the loss cost, the postulated local minimum is either very weak or at infinity.

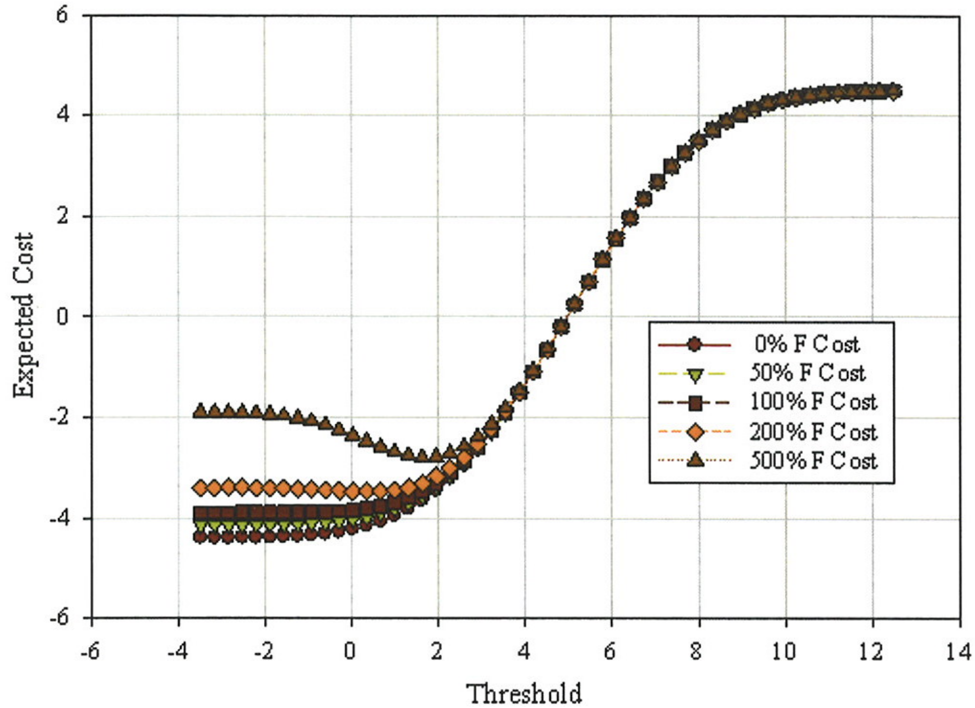

Figure 6. Expected Cost Versus Threshold for Various Fratricide Costs and 10% Friendlies

We see that the cost is negative in the initial region, transitioning from positive to negative in the middle region, and positive in the final region. This overall behavior is dominated by the effective negative cost of killing an enemy before he can do damage.

From these computations, we see that for a situation where mission is more critical than fratricide, the ATR can be tuned anywhere in the flat, low threshold region consistent with desired technical performance. For the situation where fratricide is to be avoided, the ATR may be tuned to a local minimum.

C. Equal Friendlies

As we move to equal numbers of friendlies (Fig. 7), we see the shape of the curve changing to reflect the increase in friendly probability. So long as fratricide is not costly, the curve is essentially the same as for few friendlies. However, as the cost of fratricide increases, the expected cost rises rapidly, making the minimum even more pronounced.

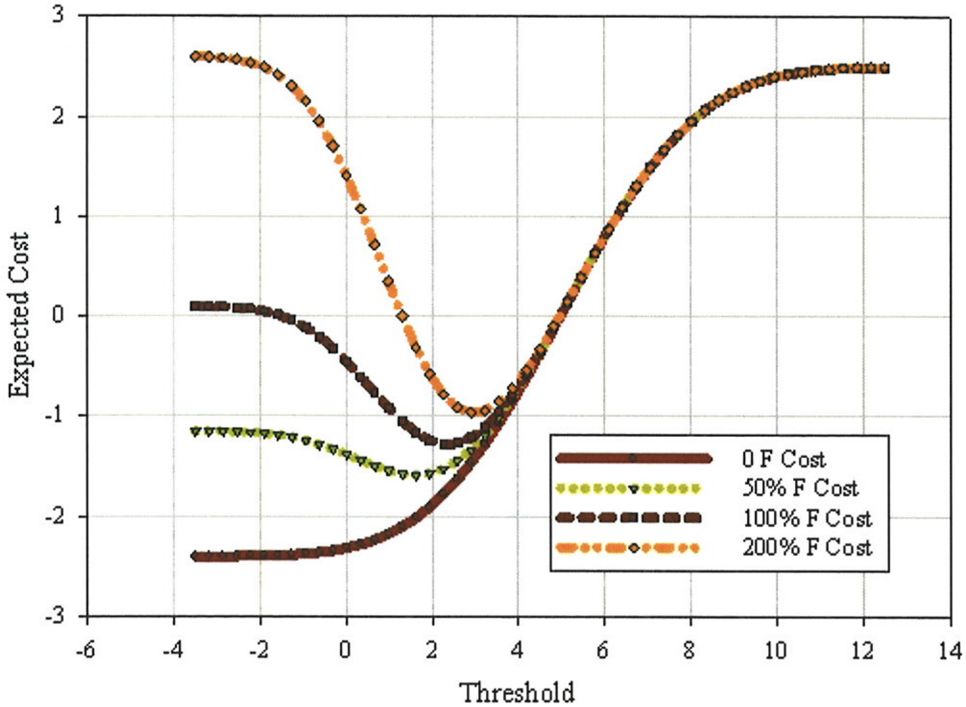

Figure 7. Expected Cost Versus Threshold for Various Fratricide Costs and 50% Friendlies

D. Many Friendlies

This situation is shown in Figure 8. In this case, the expected cost again rises very rapidly with increasing fratricide cost, but the minimum is quite weak. Further, the shape of the curve is considerably different, reflecting the reduced probability of enemy.

E. Consolidation

In observing these parametric computations, we observe that as the cost of fratricide increases, the minimum appears to move from (approximately) the friendly mean towards the target mean. Further, we see that this motion is relatively slow under change in friendly-to-target ratio.

The issue of cost turns on a trade between the loss incurred by not killing a target (and avoided if the target is killed) and the cost of fratricide. Clearly, the cost of fratricide (or amicide) is largely inestimable, but depending on circumstance either quite large or negligibly small, we may draw some insight from the trends here.

If we are dealing with a situation where we cannot count the costs of fratricide, so critical are the necessities of mission and effectiveness, then we may draw insight from the limit of

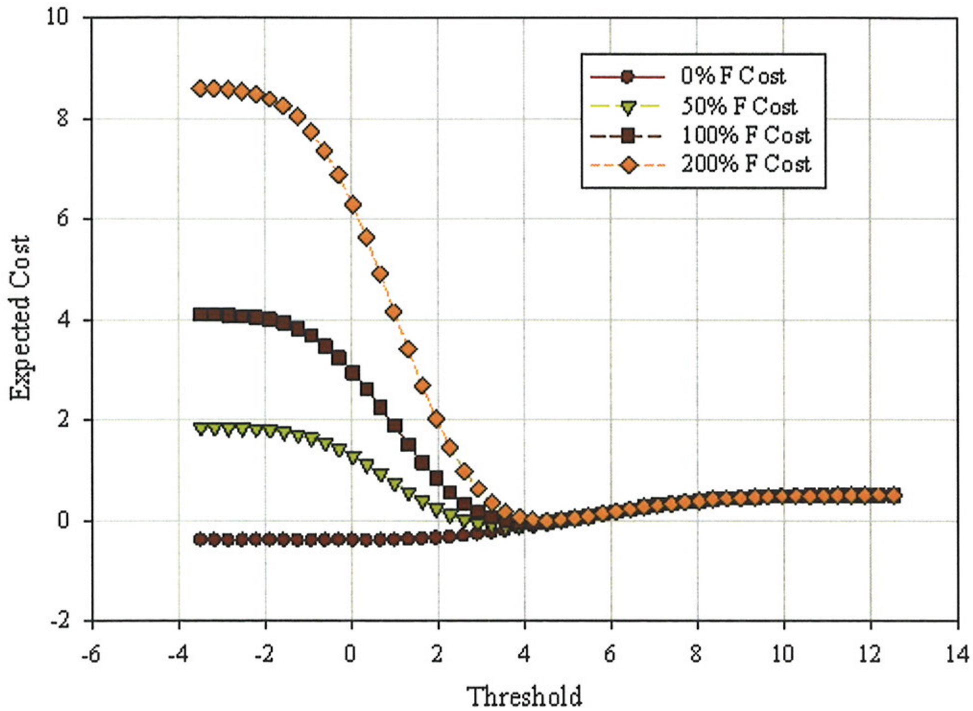

Figure 8. Expected Cost Versus Threshold for Various Fratricide Costs and 90% Friendlies

small fratricide cost. Based on the computations presented, this would indicate that we might want to place our threshold at approximately the friendly mean.[4] Since this seems to be likely associated with a high-target demographic, we may surmise this minimum to be weak and insensitive to local variation of a few percent in friendly density.

If we are dealing with a situation where the costs of fratricide are enormous, then based on these computations, a threshold of the order of the midpoint between the two means seems in order. Again, if we associate this situation with a preponderance of friendlies, such as we might find in a terrorist situation, a higher threshold, even up to the target mean may be appropriate, although in this case more attention to the loss cost may be indicated. How many casualties would we have been willing to accept to preserve the World Trade Center on 9/11?

[4]This is presuming the friendly mean is less than the target mean!

REFERENCES

AMRDEC 2004	AMRDEC Letter Report "Assessment of State-of-the-Art Autonomous and Aided Target Recognition," August 2004.
Clausewitz 1976	Clausewitz, Carl von, On War, Michael Howard and Peter Paret, editors and translators, Princeton University Press, Princeton, New Jersey, 1976.
Drummond Holte 2000	Drummond, Chris, and Holte, Robert C. "Explicitly Representing Expected Cost: An Alternative to ROC Representation," in Ramakrishnan, R., & Stolfo, S., eds., Proceedings on the Sixth ACM SIGKDD International Conference on Knowledge Discovery and Data Mining, 2000.
Drummond Holte 2004	Drummond, Chris, and Holte, Robert C. "What ROC Curves Can't Do (and Cost Curves Can)," ECAI'2004 Workshop on ROC Analysis in AI, 2004.
Fawcett 2003	Fawcett, Tom, "ROC Graphs: Notes and Practical Considerations for Data Mining Researchers," Hewlett-Packard Corporation, 2003.
Flach 2003	Flach, Peter A., "The Geometry of ROC Spaces: Understanding Machine Learning Metrics through ROC Isometrics," Proceedings of the Twentieth International Conference on Machine Learning, Washington, DC, 2003.
Fowler 2004	Fowler, Bruce W., The Physics of War, 2004.
Heaston Smoots 1983	Heaston, R. J., and Smoots, C. W. "Introduction to Precision Guided Munitions," IIT Research Institute, Chicago, IL, GACIAC HB-82-01, May 1983.
Meadows 2005	Meadows, John, "Automatic Target Recognition: Army/Tri-Service Report Findings" Presentation, 2005.
Meyer-Arendt 1972	Meyer-Arendt, Jurgen R., Introduction to Classical and Modern Optics, Prentice-Hall, Inc., Englewood Cliffs, NJ, 1972.
Pickard 2004	Pickard, Julie M., "Using Receiver Operating Characteristic (ROC) Curves to Evaluate Digital Mammography," 2004.
Provost Foster 2001	Provost, Foster, and Fawcett, Tom "Robust Classification for Imprecise Environments," Machine Learning Volume 42, Number 3 (March 2001).
Taylor 1983	Taylor, James G., Lanchester Models of Warfare, Volume I, Military Applications Society, 1983.
Young 1918	Young, L. D., Lieut., Reminiscences of a Soldier of the Orphan Brigade, Courier-Journal Job Printing Company, Louisville, 1918.

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